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# ENVIRONMENTAL EFFECTS ON RELIABILITY AND MAINTAINABILITY OF AIR FORCE AVIONICS EQUIPMENT

TECHNICAL REPORT AFFDL-TR-74-113

August 1974



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This technical report has been reviewed and is approved for publication.

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Air Force Logistics Command maintenance cost and reliability data were analyzed for four categories of airplanes: cargo, fighter, trainer, and bomber. The data base included two years of operations for 33 models, and approximately 8,500 individual airplanes. Maintenance cost percentages were determined for ten major subsystems. Maintenance costs for avionics subsystems were found to be approximately 40% of all maintenance costs. which is greater than the combined total of the five next most expensive subsystems, i.e., power plant, air frame, landing gear, flight control, and fuel system. The cost to maintain just the

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environmentally induced avionics failures is comparable to the cost of maintaining any other airplane subsystem. Based on the data evaluated, the elimination of environmentally coded avionic failures on the ten major systems could increase their overall field reliability by a factor of 1.2 to 2.5. Recommendations were made to develop realistic environmental test criteria which would uncover such failure modes (and lead to correct design) before equipments become operational.

## FOREWORD

This report was prepared by the Combined Environments Group, Vehicle Equipment Division, Air Force Flight Dynamics Laboratory. The work described herein was conducted under Project 6146, Task 614604.

The authors express their appreciation to Richard Scott, ASD/ENYS, and Thomas Campbel , ASD/ENYS, who did the bulk of the data reduction.

The performance period for the work was from December 1973 to April 1974. This report was submitted May 1974 by the authors.

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# I. INTRODUCTION

The majority of avionics equipment items must undergo environmental qualification tests and reliability demonstration tests as stated in MIL-STD-810 or MIL-E-5400 and MIL-STD-781. The purpose of these tests is to verify that the avionics item will operate in the service environment and that the service MTBF (mean time between failures) of the item corresponds to the design MTBF. However, the performance of Air Force avionics equipment in service deployment has been significantly less than the expectations placed on it prior to its field evaluation and deployment.

A recent Air Force study (Reference 1) has shown that the service MTBF of avionics equipment runs between six and ten times less than that shown by reliability calculations and demonstration tests. In fact the MTBF of six major avionics subsystems in one modern all weather fighter is 20 times less than specified in the contract and shown in their reliability demonstrations. Avionics equipment in several recently developed aircraft have not reached service deployment without extensive modifications due to premature failures and malfunctions that have occurred during category II flight tests, all weather evaluation flight tests (References 2, 3, 4, 5, 6, and 7). These avionics equipment items had been developed under current environmental qualification testing methods.

The demonstrated poor correlation between test and field performance has fostered the notion that these tests can be waived or at best run as an attempt to satisfy tradition. When a test is conducted and

failures occur they are frequently classified by the contractor as nonrevelant or random failures because of the belief that the tests are unrealistic. However, a recent study has shown that some field failure modes are detected by this same testing criteria (Reference 8). The difficulty lies in trying to separate nonrelevant test induced failures from those failures that occurred in the test which will appear in service if corrective action is not taken.

The failure of environmental qualification and reliability demonstration tests to detect environmentally sensitive avionics equipment results in increased maintenance costs, mission aborts, increased spare part inventories and ECP programs. The objective of this report is to quantify the impact of environmentally induced avionic failures on maintenance cost and to determine the effect of environmental stresses on avionics equipment MTBF. This analysis indicates the potential maintenance cost savings that can result from developing and applying new realistic testing of avionic equipment.

## II. ANALYSIS OF AIR FORCE MAINTENANCE AND RELIABILITY DATA

### 1. MAINTENANCE COST

Air Force Logistic Command (AFLC) AFM-66-1 data was used as a data base for determining the impact of environmentally caused avionics equipment failures. This data includes day to day logistic support costs incurred to support a weapon system: base labor, base materials, depot labor, depot material, cost of condemnations, transportation and pack/ship costs (Reference 9). The logistic support costs of the major Air Force airplane weapon systems were grouped into four classes of weapons. The airplane models included in each class are shown below:

A. Cargo (C-5A, C-9A, C-130A, C-130E, C-131, C-141A, HC-130H, KC-135A)

B. Fighter (A-7D, F-4C, F-4D, F-4E, F-100, F-102, F-104, F-105D, F-105F, F-106, F-111A, F-111D, F-111E, F-111F, FB-111A, RF-4C)

C. Trainer (A-37, T-29, T-33A, T-37, T-38, T-39)

D. Bomber (B-52G, B-52H, B-57)

For analysis purposes each airplane was assumed to be made up of ten subsystem categories: airframe, flight control, landing gear, power plant, environmental control, electrical hydraulic, fuel, avionics, weapon delivery and miscellaneous. The components and subsystems included in each of these major airplane systems, except avionics, were the same as used in the AFM-66-1 data product number K051 PW4L. The avionics system was expanded to include some equipment not normally considered as avionics but do contain a significant amount of electronics.

The avionics equipment category included: autopilot, instruments, HF communications, UHF communications, interphone, IFF, radio navigation, bombing navigation, fire control and electronic countermeasure subsystems (ECM).

Table I shows the distribution of maintenance costs for Air Force airplanes during calendar years 1972 and 1973. Approximately 39 percent of the cost of maintaining the Air Force fleet was used to maintain avionics equipment.

TABLE I. AIR FORCE MAINTENANCE COST DISTRIBUTION BY AIRPLANE SUBSYSTEM

| Airplane Subsystem | CY 1972 Percentage of Total Cost | CY 1973 Percentage of Total Cost |
|---|---|---|
| Airframe | 8.8 | 9.3 |
| Flight Control | 4.9 | 4.2 |
| Landing Gear | 6.8 | 6.6 |
| Power Plant | 13.6 | 13.6 |
| Environmental Control | 2.2 | 2.0 |
| Electrical | 3.0 | 2.8 |
| Hydraulic | 2.0 | 1.5 |
| Fuel | 3.6 | 2.9 |
| Avionics | 40.5 | 38.5 |
| Weapons Delivery | 1.6 | 1.6 |
| Miscellaneous | 13.3 | 16.5 |

The distribution of maintenance costs among the four airplane categories is shown for calendar year 1973 in Table II. Observe how

most airplane categories have approximately the same percentage of total maintenance costs spent on a given subsystem. For example, the flight control system for all airplane types is about 5 percent and the environmental control system is about 2 percent. However, the maintenance costs for avionics equipment is different for each airplane category which reflects both the complexity and quantity of avionics equipment carried by the airplane category. The marked perturbations in the maintenance costs of the trainer airframe and power plant subsystems from other airplane categories can be interpreted by considering how this airplane is used.

TABLE II. PERCENT OF TOTAL MAINTENANCE COST OF EACH AIRPLANE CATEGORY SPENT ON EACH AIRPLANE SUBSYSTEM (CY 1973)

| | Airplane Category | | | |
|---|---|---|---|---|
| Airplane Subsystem | Trainer | Cargo | Bomber | Fighter |
| Airframe | 15.1 | 6.3 | 9.6 | 5.9 |
| Flight Control | 4.9 | 3.3 | 4.2 | 4.5 |
| Landing Gear | 8.7 | 5.3 | 6.7 | 5.5 |
| Power Plant | 24.7 | 11.0 | 9.7 | 9.0 |
| Environmental Control | 2.3 | 2.0 | 1.6 | 2.2 |
| Electrical | 4.3 | 1.6 | 3.4 | 1.8 |
| Hydraulic | 1.0 | 1.5 | 1.7 | 1.6 |
| Fuel | 2.9 | 3.0 | 2.7 | 3.1 |
| Avionics | 21.6 | 31.4 | 47.4 | 53.4 |
| Weapons Delivery | 0.4 | 1.3 | 0.4 | 4.3 |
| Miscellaneous | 13.7 | 32.0 | 11.5 | 8.6 |

Trainer airplanes perform more short duration missions with significantly more landing and take-off cycles than other airplanes, as shown in Table III. Landing and take-off cycles are generally more severe on both the airframe and jet engines which is reflected in the higher maintenance cost percentages for the trainer category.

TABLE III. AVERAGE AIRPLANE FLIGHT HOURS PER LANDING (CY 1973)

| Trainer | Cargo | Bomber | Fighter |
|---|---|---|---|
| 0.6 | 1.4 | 4.2 | 1.5 |

2. AVIONICS EQUIPMENT FAILURES

Avionics failures that occur in the field were analyzed using the Maintainability Reliability Summaries that AFLC compiles on all major airplane systems (Reference 10). This data is accumulated from the field to provide management visibility for timely and effective improvements of reliability in operationsl systems. The data provides a capability to evaluate cost, safety and availability of weapon systems. Although the data system was not established for detailed engineering analysis purposes, estimates of environmental and other engineering deficiencies can be made.

A total of 17 different airplane models were selected for the avionics field failure analysis. Airplanes were selected so that at least two airplane models were in each airplane category as shown below:

A. Cargo (C-5A, C-130E, C-141, KC-135)

B. Fighter (A-7D, F-4C, F-4D, F-105D, F-105F, F-111A, F-111D, F-111E, FB-111A)

C. Bomber (B-52G, B-52H)

D. Trainer (T-37, T-38)

Maintainability Reliability Summaries classify each failure by a series of descriptive codes called how-mal codes (how-malfunction codes). These codes characterize the cause of each failure for each avionics subsystem. For this study these how-mal codes were divided into two categories -- environmentally induced failures (those caused by vibration, temperature, humidity, sand and dust, and pressure) and unknown caused failures. Examples of how-mal codes attributed to environmental causes were corrosion, leaking, loose, dirty, broken and cracked. Examples of how-mal codes which were attributed to unknown causes were adjustment improper, failed to operate, failed automatic test, internal failure, and video faulty. Observe that only those how-mal codes which clearly indicate an environmental influence were classified as environmentally caused failures. However, a significant number of those failures attributed to unknown causes probably are environmentally induced since broad how-mal codes such as failed to operate and internal failures do not specify the cause of the failure. Therefore, this method of just looking at these broad brush how-mal codes gives a low estimate of the true number of environmentally caused failures. This approach gives a lower bound to the actual extent of environmentally induced failures. Table IV shows the percentage of avionics failures caused by environmental effects for each airplane category.

Other investigators who limited their studies to only one aircraft model found that 52 percent of one Navy fighter's avionics failures

(Reference 8) and 60 percent of one Air Force bomber's ECM failures (Reference 11) were due to environmental effects. The data used for these studies contained detailed information concerning the failure mechanisms of avionics equipment. One study was based upon the analysis of the field failure engineering reports on 175 individual aircraft (Reference 8). The other study investigated one Air Force bomber squadron by analyzing data from a special expanded field failure data reporting system (Reference 11). Although the airplane models analyzed in these two studies were significantly different, the percentages of avionics failures caused by environmental effects were approximately the same. This suggests that if detailed failure data were available and analyzed on the avionics equipment used in all the airplane models considered in this study, the results would be comparable. Therefore, it is reasonable to assume that the true extent of environmentally caused avionics failures is most reflected by the results of these two detailed studies. However, since this detailed data is not available and based on the analysis in this report, it is reasonable to assume that the average percentage of avionics failures in Air Force airplanes caused by environmental effects for the entire inventory is probably between 14.6 and 60 percent.

TABLE IV. PERCENT OF AVIONICS FAILURES THAT ARE ENVIRONMENTALLY INDUCED (March 1973 to February 1974)

| Airplane Category | Lower Bound Percent |
|---|---|
| Trainer | 19.8 |
| Fighter | 15.4 |
| Bomber | 12.0 |
| Cargo | 11.3 |
| Average | 14.6 |

Equipment failures do not necessarily cause all airplane maintenance actions. Some actions are normal routine check, minor adjustments or removal of a piece of equipment to get at another piece of equipment. Therefore, to relate environmentally caused failures to maintenance costs, the percentage of maintenance actions due only to equipment failures had to be determined. This was obtained from the Maintainability Reliability Summaries by dividing the number of avionic failures per thousand flight hours by the number of maintenance actions per thousand flight hours. Table V shows the results of these calculations for each airplane category. This table shows that on the average 60.6 percent of all avionic maintenance actions are due to failures.

TABLE V. PERCENT OF AVIONICS EQUIPMENT MAINTENANCE ACTIONS CAUSED BY AVIONICS FAILURES (March 1973 to February 1974)

| Airplane Category | Percent Caused by Failures |
|---|---|
| Bomber | 64.6 |
| Fighter | 48.6 |
| Cargo | 64.6 |
| Trainer | 64.9 |
| Average | 60.6 |

The range of avionics maintenance action caused by environmentally induced failures is shown in Table VI. The lower bound was determined using only those how-mal codes which positively indicated that the failure was induced by the environment. The upper bound was determined assuming that the actual extent of avionics failures induced by environmental effects is reflected by the failure percentages found in the Air Force bomber.

TABLE VI. PERCENT OF AVIONICS MAINTENANCE ACTIONS CAUSED BY ENVIRONMENTALLY INDUCED AVIONICS FAILURES (March 1973 to February 1974)

| | |
|---|---|
| Lower Bound | = 14.6% X 60.6% = 8.8% |
| Upper Bound | = 60% X 60.6% = 37.0% |

3. ENVIRONMENTALLY CAUSED AVIONICS EQUIPMENT MAINTENANCE COSTS

The cost of environmentally induced avionics equipment failures can be estimated using the results of the previous two sections. Table VI

gives the percent of avionics maintenance actions caused by environmental effects. Table I gives the percent of total maintenance costs that are used on avionics equipment. The product of these two percentages gives the percent of total maintenance costs caused by environmentally induced avionics failures. This approach equally weights the cost of routine adjustments and the repair of a piece of avionics equipment. Normally repair of a piece of equipment is significantly more time consuming and costly than routine part replacement or equipment adjustment. Therefore this analysis tends to under estimate the true cost of a failure. Table VII shows the results of this analysis.

TABLE VII. PERCENT OF AIR FORCE MAINTENANCE COSTS CAUSED BY ENVIRONMENTALLY INDUCED AVIONICS EQUIPMENT FAILURES (CY 1973)

| | |
|---|---|
| Lower Bound | |
| | = 38.5% X 8.8% = 3.4% |
| Upper Bound | |
| | = 38.5% X 37% = 14.3% |

The significance of the results shown in Table VII are apparent when these percentages were compared in Table VIII to maintenance costs associated with other airplane subsystems as presented in Table I. Observe that the upper bound of environmentally induced avionics failures is greater than the maintenance costs of all other airplane subsystems. The lower bound value is greater than 5 other major airplane subsystems.

## VIII. COMPARISON OF AIR FORCE ENVIRONMENTALLY INDUCED AVIONICS FAILURES TO OTHER AIRPLANE SUBSYSTEM MAINTENANCE COSTS

| Aircraft Subsystems | CY 1973 Percentage of Total Maintenance Costs |
|---|---|
| Upper bound of Environmentally Caused Avionics Failures | 14.3 |
| Power Plant | 13.6 |
| Airframe | 9.3 |
| Landing Gear | 6.6 |
| Flight Control | 4.2 |
| Lower bound of Environmentally Caused Avionics Failures | 3.4 |
| Fuel | 2.9 |
| Electrical | 2.8 |
| Environmental Control | 2.0 |
| Weapons Delivery | 1.6 |
| Hydraulic | 1.5 |
| Miscellaneous | 16.5 |

## III. IMPACT OF ENVIRONMENTALLY CAUSED FAILURES ON THE MTBF OF AVIONICS EQUIPMENT

The field MTBF of individual avionics equipment can be determined directly from the Maintainability and Reliability Summaries by dividing the flight hours by the number of failures. In section II it was shown that between 14.6 and 60 percent of avionics failures were environmentally induced. Based on the avionic systems analyzed Table IX shows that their field MTBF could be increased by a factor of 1.2 to 2.5 by eliminating the failures coded as environmentally induced. In view of the fact that other failures may also have been environmentally induced this indicates the strong impact environmental stresses have on avionics equipment reliability.

TABLE IX. RANGE OF INCREASE FOR AVIONICS EQUIPMENT MTBF BY ELIMINATION OF ENVIRONMENTALLY CAUSED FAILURES

$$\text{MTBF}^* = \frac{\text{\# of Flight Hours}}{\text{\# of Non Env. Caused Failures}} = \frac{\text{MTBF}}{1-Z}$$

$$\text{Upper Bound of MTBF}^* = \frac{\text{MTBF}}{1-0.60} = 2.5\ \text{MTBF}$$

$$\text{Lower Bound of MTBF}^* = \frac{\text{MTBF}}{1-0.14} = 1.2\ \text{MTBF}$$

*MTBF With No Environmentally Caused Failures

Z = Fraction of Avionics Failures That Are Environmentally Caused

# IV. SUMMARY AND CONCLUSIONS

Maintenance of environmentally caused avionics equipment failures has been found to be consuming between 3.4 and 14.1 percent of Air Force maintenance money. It was shown that both the lower and upper bound estimates for the maintenance cost of environmentally induced avionics failures are equivalent to the cost of maintaining most other major subsystems in an Air Force airplane. Specifically, the upper bound estimate is greater than the maintenance cost of any other major subsystem. Furthermore, it was determined that environmentally induced failures decrease avionics reliability by a factor of 1.2 to 2.5.

Since most avionics equipment items undergo environmental qualification and reliability demonstration tests prior to service deployment, it must be concluded that current test methods lack effectiveness in screening out environmentally sensitive equipment. The results of this study show that substantial life cycle cost and significantly increased equipment reliability benefits can result from the development of adequate test methods.

## V. RECOMMENDATIONS

It is recommended that new environmental test criteria for avionics equipment be formulated that would identify environmental sensitive equipment before it reaches field deployment. This criteria should be developed only after sufficient engineering analysis and laboratory testing has been completed so that a high degree of confidence exists that the developed criteria does identify environmental sensitivity equipment.

A logical rational engineering approach to developing new environmental criteria must include the following tasks: (1) Measure and analyze the environmental conditions that avionics equipment have to perform under, (2) conduct exploratory research to develop the required environmental simulation techniques, and (3) develop prediction methods which would allow the test condition to be structured to a particular application.

This approach to obtaining realistic environmental testing criteria has been successfully used by the AF Flight Dynamics Laboratory in its development of the new random vibration qualification test criteria that will be included in the C version of MIL-STD-810, Environmental Test Methods. This approach is also currently being applied by the AF Flight Dynamics Laboratory to develop realistic temperature, altitude, and humidity environmental test criteria which simulate the flight environments of avionics equipment.

The establishment, validation and adoption of these new test procedures and new test criteria are expected to cause realistic assessment of equipment for the Air Force environment. This, in turn, will cause required improvement in equipment design and in its controlled environment. The end result will be significantly reduced life cycle logistic maintenance and repair costs for Air Force equipments.

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